CNY-CNH Term Spread and Covered Interest Parity Deviation

Penghao Cheng & Qing Ge
University of California, Santa Cruz

May 7, 2019

Abstract

China has not only both onshore and offshore money (capital) markets, but also both onshore and offshore currency market. The differences between onshore and offshore RMB markets would cause a lot of questions that are worth probing into. This paper implements a simple model to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential of money market and CIP violation of currency market spillover effects. The empirical test uses a new flexible econometric method - Bayesian local projections which can sensibly reduce the impact of compounded biases over the horizons and effectively deal with model misspecifications. The results are three-fold: First, one market shock can transmit to the other market through capital flows. The shocks from forward currency market have a large impact on the spot money market through capital flows. The effects on both markets would die away in a week after initial shocks, but the effect on capital flows is less persistent. Second, cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore. Third, a large amount debt issuance may decrease the absolute value of the net deviation.

1 Introduction

The influence of RMB has been growing in recent years as the Chinese economy expanding after the financial crisis. According to the latest Bank of International Settlements Triennial Central Bank Survey on the foreign exchange market, RMB now ranks as the worlds sixth most traded currency. For several years Chinese authorities have argued for the desirability
of an alternative to the U.S. dollar as the key reserve currency, so that they are now moving in the direction of reducing their dependence on the U.S. dollar by internationalizing RMB. The internationalization of RMB may gain benefits such as decreasing exchange risks of international trade and investment, thereby reducing transaction costs, the People’s Bank of China (PBoC), the central bank of China, founded offshore markets as a trial of RMB internationalization and a harbinger for domestic financial system liberalization in Hong Kong since 2010 which is known as the CNH market. Unlike the onshore foreign exchange market (CNY market), the offshore market (CNH market) is a relatively efficient market without restrictions in onshore market.

This study is motivated to examine China’s consistent onshore-offshore CIP deviations by particular shocks. Liao [2016] decomposes the CIP deviations to money market deviations and currency market deviations. In his model, the firm could choose issue bonds in one market, either in Euro market or US market, to minimize the borrowing cost. Furthermore, the money market shocks or currency market shocks would affect the decision of this firm. However, this paper adds the financing time cost of bank to fit the scenario of China onshore and offshore markets, which means bank would issue bonds in both onshore and offshore market. Following Liao [2016], this paper modifies his model to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential and CIP violation spillover effects. This static model includes three agents - a bank, investors in money market, and traders in currency forward market. Onshore and offshore specialized investors actively allocate asset in money market and forward arbitrage trader make profit through CIP deviations in currency forward market. Further, a representative bank connects these two markets by engaging FX hedge debt allocation. When the onshore relative to offshore credit spread (term spread) is high, the bank allocates a greater share of RMB debt in offshore market. An increase in offshore CNH, however, generates CNH exposure, which the bank hedges through currency forwards. Alternatively, when CIP deviations (transaction cost) are large, the bank chooses to minimize borrowing costs (credit spread cost and transaction cost) and financing time cost simultaneously and then decides on the optimal share. The two violations of money and currency markets are the main consideration of the representative bank for debt issuance.

This paper estimates two types of exogenous shocks affect this system. First, bond demand shocks in money market are caused by monetary policy, investor preference, and money market regulatory. Second, non-issuance-related use of currency forward contracts shocks in currency forward market includes central bank policy - FX intervention, trader expectation driven hedging and arbitraging demands, and currency market regulatory - capital control.
Other literatures on China’s foreign exchange rate has not covered the capital control policy using a daily index to measure the level effect of the deviation from covered interest parity. This paper aims to fill that important void. These two shocks have spillover effects from RMB spot market (money market) to forward market (currency market), and the other way around.

In money market, this paper uses offshore-onshore term spread deviations $c = (r^a_{off} - r^a_{on}) - (r^{o/n}_{off} - r^{o/n}_{on})^1$ to measure money market gaps. The Figure 1 shows RMB and USD exchange rate in onshore and offshore currency market. There were persistent discrepancies in the pricing of currency exchange forward between $F_{on}$ and $F_{off}$ before 8/10/2015. After that, but before 7/5/2017, spot exchange rates $S_{on}$ and $S_{off}$ existed significant gaps during some periods. Currently, the converging power shows in both onshore and offshore, and spot and forward exchange rate. In currency market, this paper calculates onshore-offshore CIP deviations $b = r^{o/n}_{on} + s - f - r^{o/n}_{off}$ to estimate currency market gaps, where the spot exchange rate between onshore CNY and offshore CNH is $1 + s \equiv \frac{S_{on}}{S_{off}}$ and the forward exchange rate is $1 + f \equiv \frac{F_{on}}{F_{off}}$. The money market offshore-onshore term spread deviations and currency market onshore-offshore CIP deviations are displayed in Figure 2.

---

Figure 1: $S_{on}$: onshore spot exchange rate RMB/USD; $S_{off}$: offshore spot exchange rate RMB/USD; $F_{on}$: one-year onshore deliverable forward exchange rate RMB/USD; $F_{off}$: one-year offshore non-deliverable forward exchange rate RMB/USD.

---

1If $c = (r^a_{off} - r^a_{on}) - (r^{o/n}_{off} - r^{o/n}_{on})$, this equation can be interpreted to overtime offshore-onshore credit spread deviation.
Figure 2: on 1/12/2016 $c = -57.9054$, $b = -61.04023$; on 1/5/2017 $c = -52.4599$, $b = -54.8629$; on 6/1/2017 $c = -21.1185$, $b = -21.14572$

Figure 3: offshore-relative-to-onshore total cost

Figure 3 reveals the consideration of representative bank that faces the total funding cost of offshore relative to onshore. Before 8/10/2015, offshore funding was better than onshore for this representative bank. Between 8/11/2015 and 7/5/2017, this representative bank
would prefer to issue onshore bond rather than borrow offshore money, due to positive gaps \( c - b > 0 \). Nowadays, the gaps are more random deviation. This paper is structured as follows: literature review in part two; modeling bank’s strategy in onshore-offshore RMB money and currency markets in part three; empirical data analysis and Bayesian local projections in part four; conclusion in the last part.

2 Literature review

The expanding Chinese currency forward markets have revitalized research interest in the capital control effect on onshore-offshore carry trades and the significance of CIP deviation. Existing studies on onshore and offshore foreign exchange markets tend to focus on causality between the two, e.g. Burdekin and Tao [2013]. They used Granger causality test on the onshore-offshore spread. By cointegration method Ding et al. [2014] found that price discovery is absent between the onshore and offshore spot markets, however the price discovery exists between onshore spot and offshore nondeliverable forward (NDF) rates. Owyong et al. [2015] implemented bidirectional linear and nonlinear causality on several sets of spot and forward prices. Their results suggest stronger causality running from the spot onshore rate to the spot offshore rate than vice versa, which implies foreign impulses have had an influence on the domestic market. Despite trading and capital restrictions, Peng et al. [2007] found that sentiment can spill over between the onshore and offshore markets and that over time the relative contribution of price leadership has shifted between the onshore and offshore centers.

GARCH model is another quantitative method used in the research. Maziad and Kang [2012] employed a bivariate GARCH model to understand the inter-linkages between onshore and offshore markets and found that, while developments in the onshore spot market exert an influence on the offshore spot market, offshore forward rates have a predictive impact on onshore forward rates. Funke et al. [2015] implemented an extended GARCH model to measure the policy effect on both conditional level and volatility of CNH-CNY spread. Cheung and Rime [2014] use specialized microstructure dataset to study the CNH exchange rate dynamics and its links with onshore exchange rates (CNY). They conclude that the offshore CNH exchange rate has an increasing impact on the onshore rate CNY and significant predictive power for the official RMB central parity rate. Craig et al. [2013] attribute the CNH-CNY price differential to onshore investor risk sentiment and capital account liberalization. They applied an asymmetric self-excited threshold auto-regression (SETAR) model to the daily CNY-CNHN price differential from September 2010 to January 2013 and found
limited integration between CNY and CNH market. These literature conclude the existence of CIP deviation on both onshore and offshore RMB forward markets.

Addition to these literatures on the research for the correlation of RMB FX markets, two kinds of literatures focusing on the deviation of CIP through decomposition to investigate the market segmentation. The first strand is that the liquidity of global market affects the funding of arbitrage and then induces the deviation. Ivashina et al. [2015] concludes that banks can borrow in euros and swap into dollars to make up for the dollar shortfall, but this may lead to violations of covered interest parity when there is limited capital to take the other side of the swap trade. Bräuning and Ivashina [2016] further explore the role of monetary policy in affecting global bank’s funding sources and the use of FX hedges. Iida et al. [2016] provide theoretical evidence to show that monetary policy divergence between the Federal Reserve and other central banks widens CIP deviations and that regulatory reforms such as stricter leverage ratios raise the sensitivity of CIP deviations to monetary policy divergence by increasing the marginal cost of global banks’ USD funding. Cetorelli and Goldberg [2012] report that global banks actively manage liquidity using internal cross-border financing in response to domestic shocks. The other strand is the banking sector issues. Sushko et al. [2017] and Du et al. [2016] focus on the banking sector, and the ability of banks to take on leverage. The key message is that the value of dollar plays the role of barometer of risk-taking capacity in global capital markets. When the dollar strengthens, CIP deviations widen. Du et al. [2016] formally establish CIP arbitrage opportunities that cannot be explained away by credit risk or transaction costs, and present evidence that bank balance sheet costs and asymmetric monetary policy shocks are the primary drivers of CIP deviations. Borio et al. [2016] construct empirical proxies for net hedging demand of different national banking systems and show that they are consistent with the cross-sectional variations in CIP deviations. Liao [2016] documents economically significant and persistent discrepancies in the pricing of credit risk between corporate bonds denominated in different currencies. This violation of the Law-of-One-Price (LOOP) in credit risk is closely aligned with violations of covered interest rate parity in the time series and the cross-section of currencies. One recent work Ho et al. [2018] applied Mixture of Distribution Hypothesis and Veronesi [1999]’s theory to the exchange rate market and examine the respond of exchange rate volatility to the market information.
3 A model of onshore-offshore money market and currency market deviations

This static model includes three agents (bank, investors in money market, and traders in currency forward market) and two exogenous shocks. Bank issues bonds in onshore and offshore money market and uses currency forward to hedge offshore bond issuance. The representative bank minimizes borrowing cost and financing time cost to choose the share of onshore issuance. Investors in onshore and offshore money market buy bonds. Investors would maximize investment return to choose the investment amount. Traders in currency forward market do carry trade with forward contract. Traders would also maximize investment return to choose the investment amount. εc is offshore-relative-to-onshore bond demand shock in money market. Furthermore, εb is other non-issuance-related use of currency forward contracts shock in currency forward market.

3.1 Bank decision

A bank chooses a fixed amount of RMB debt $D$ that needs to be borrowed and faces two costs for issuing onshore-relative-to-offshore bonds: term spread differential onshore and offshore RMB $-c = (r^a_{on} - r^{o/n}_{on}) - (r^a_{off} - r^{o/n}_{off})$, and transaction cost (CID) across the onshore and offshore boundary $b = r^{o/n}_{on} + s - f - r^{o/n}_{off}$. For term spread differential, one is the onshore CNY bond yield $r^a_{on}$. The other is offshore CNH bond yield $r^a_{off}$ in offshore financial centers like Hong Kong, Singapore or London. Then, the bank observes a credit spread differential between onshore and offshore RMB bond yields to adjust risk free interest rate difference denoted as $-c = (r^a_{on} - r^a_{off}) - (r^{o/n}_{on} - r^{o/n}_{off})$, which also measures the interest rate term spread differential. If money market doesn’t have arbitrage opportunity, the credit/term spread $c = 0$ fails most of the time due to market segmentation. For transaction cost (CID), furthermore, if the bank borrows money from offshore market, it has an add-on cost $b$ across the onshore and offshore boundary. This paper uses the U.S. currency as a bridge to measure this transaction cost $b$. If CIP holds between CNY/CNH and USD, it means $(1 + r^a_{on}) = \frac{F_{on}}{S_{on}} (1 + r^a_{us})$ and $(1 + r^{o/n}_{on}) = \frac{F_{off}}{S_{off}} (1 + r^a_{us})$, where $S_{on}$ or $S_{off}$ is spot exchange rate and $F_{on}$ or $F_{off}$ is forward exchange rate both expressed in onshore CNY or offshore CNH per USD. Then the spot exchange rate between onshore CNY and offshore CNH is $1 + s \equiv \frac{S_{on}}{S_{off}}$ and the forward exchange rate is $1 + f \equiv \frac{F_{on}}{F_{off}}$. If currency forward market onshore-offshore RMB CIP holds, the transaction cost $b = r^{o/n}_{on} + s - f - r^{o/n}_{off} = 0$ which means there would be no carry trade opportunity. What’s more, if the onshore issuance
share $\mu$ deviates the threshold share $\theta$, it would cause financing time cost $\omega$. Therefore, the bank chooses onshore issuance share $\mu$ to minimize onshore-relative-to-offshore bond cost and financing time cost.

\[
\min_{\mu} \left( -c \underbrace{\text{interest rate term spread diff}}_{\text{onshore}} + b \underbrace{\text{transaction cost}}_{\text{transaction cost}} \right) \mu D + \frac{\omega}{2} \left( \theta - \mu \right)^2
\]

which has the solution $c - b = \frac{\omega(\mu - \theta)}{D}$.

First, if the net deviation is more negative $c - b \downarrow$, then the bank chooses a lower onshore issuance share $\mu \downarrow$ because onshore issuance is costly, otherwise it chooses $\mu \uparrow$. Second, if the total amount of debt $D$ is large enough, then $c - b$ is driven to zero as a result of arbitrage. According to these two derivations, two deviations $c$ and $b$ are aligned when large amount of cross market capital flows exist.

### 3.2 Money markets

There exists three main market participants: active offshore investors, active onshore investors and the representative bank from above that has access to both onshore and offshore money markets. Offshore active investors focus on the investment of offshore money market, and onshore investors invest in onshore money market exclusively. Investors borrow at the risk free interest rate, $r_{i}^{o/n}$ and invest at money market with a guaranteed yield to maturity of $r_{i}^{a}$, where $i$ represents either onshore or offshore. The two bonds have an identical default probability $\pi$, loss-given-default $L$. The payoff of bonds has a variance of $V$, which is treated as an exogenous constant in the model for tractability. Onshore and offshore investors have a mean-variance preference with identical risk tolerance $\tau$ and choose investment amount $X_i$ to solve the following

\[
\max_{X_i} \left[ X_i \left( (1 - \pi) r_{i}^{a} - \pi L - r_{i}^{o/n} \right) - \frac{1}{2\tau} X_i^2 V \right]
\]

which has the solution $X_i = \frac{\tau}{V} \left( (1 - \pi) r_{i}^{a} - \pi L - r_{i}^{o/n} \right)$ for $i = \text{onshore or offshore}$.

**Money market clearing conditions**
There are exogenous offshore-relative-to-onshore bond demand $\varepsilon_c$, perhaps representing demand shocks that emerging from monetary policy, investor preference, and money market regulatory. Combining the demand with bank supply showed earlier, the market clearing conditions for onshore and offshore money markets are

$$X_{on} = \mu D$$  \hspace{1cm} (3)  

$$X_{off} + \varepsilon_c = (1 - \mu)D$$  \hspace{1cm} (4)

Combining the investor demands with the market clearing conditions and applying first-order Taylor approximation for $\pi$ around 0, money market section can derive the CNH-CNY interest rate term spread differential as:

$$c = \frac{V}{\tau} \left( (1 - 2\mu)D - \varepsilon_c \right)$$  \hspace{1cm} (5)

The interest rate term spread differential $c$ represents arbitrage opportunity in money market since the default probability and loss given default are identical for the two bonds. Eqs.(5) induces that $c$ is determined by the net bond supply between offshore and onshore money markets multiplied by the elasticity.

### 3.3 Currency forward market

This section describes the dynamics of the currency forward market. The insight is similar to that of money market violation, but deviation in CIP is limited by intermediary collateral and capital constraints. There are two main participants in this market: currency forward traders and issuers.

Currency forward traders choose amount of capital to allocate to either CIP deviation, denote as $b$, or alternate investment opportunity with profit of $f(I)$, where $I$ is the amount of investment. The arbitrage has to set aside a haircut $H$ when it enters the forward transaction to trade the CIP violation. Following Garleanu and Pedersen [2011], the amount of haircut is assumed to be proportional to the size $s$ of the forward position, $H = \gamma |s|$. So,
the capital allocated towards alternative investment is $I = W - \gamma|s|$. Forward traders have total wealth $W$ and maximize the following

$$\max_s bs + f(W - \gamma|s|)$$

which generates the direct result that the expected benefit from carrying an extra unit of CIP arbitrage is equal to marginal profitability of the alternative investment, $b = \text{sign}[s]\gamma f'(W - \gamma|s|)$. In a simple case, assume the alternative investment activity is quadratic, $f(I) = \phi_0 - \frac{1}{2}\phi I^2$, $b = \text{sign}[s]\gamma(\phi_0 - \phi W + \gamma\phi|s|)$.

The model makes a further simplifying assumption that CIP deviation $b$ is linearly related to the net demand for forwards, equivalently to stating $W = \frac{\phi_0}{\phi}$, which means that arbitrageur has just enough wealth $W$ to take advantage of all positive-NPV investment opportunities in the alternative project $f(I)$. This assumption helps to reduce the constant intercept term in the equation for $b$, and derives that CIP deviation is proportional to forward trader position, $b = \phi\gamma^2 s$. The model normalizes $\phi = 1$.

**Currency forward market clearing conditions**

The representative bank from above relies on currency forward market to hedge its off-shore debt issuance - amount $(1 - \mu)D$ CNH. In addition, there are exogenous shocks to CIP basis $\varepsilon_b$ that represent other non-issuance-related use of currency forward contracts. Market clearing condition of the currency forward market shows that the equilibrium level of CIP deviation satisfies

$$\underbrace{b}_{\text{CIP basis}} = -\underbrace{\gamma^2}_{\text{haircut on collateral net hedging demand}} \underbrace{(1 - \mu)D + \varepsilon_b}_{\text{net hedging demand}}$$

Eqs.(7) indicates that CIP deviation $b$ is proportional to net hedging demand multiplied by the elasticity, which is determined by the collateral margin. Higher haircut $\gamma$ strengthened the shock of hedging demand, but without net hedging demand, $b$ does not deviate from zero.
3.4 Summary of equilibrium conditions

The three equilibrium conditions are summarized as follows (endogenous variables: \( c, b, \mu \); exogenous shocks: \( \varepsilon_c, \varepsilon_b \)):

(1) Term spread differential (offshore-onshore):

\[
\text{interest rate term spread differential} = \frac{V}{\tau} \underbrace{((1 - 2\mu)D - \varepsilon_c)}_{\text{net bond supply offshore relative to onshore}}
\]

(2) CIP basis:

\[
\text{CIP basis} = -\gamma^2 \underbrace{((1 - \mu)D + \varepsilon_b)}_{\text{net hedging demand}}
\]

(3) Bank choice of bond issuance ratio:

\[
\mu = \frac{(c - b)D}{\omega} + \theta \begin{cases} 
\text{if } c - b \uparrow, \text{ cheaper to issue in onshore} \\
\text{if } c - b \downarrow, \text{ cheaper to issue in offshore}
\end{cases}
\]

With these equilibrium conditions, this model can analyze the transmission of \( \varepsilon_c \) and \( \varepsilon_b \) shocks from one market to the other.

**Proposition 1.** *(Spillover of deviations)* If \( \varepsilon_c \downarrow \), then \( c \uparrow \Rightarrow \mu \uparrow \Rightarrow b \uparrow \). If \( \varepsilon_b \downarrow \), then \( b \uparrow \Rightarrow \mu \downarrow \Rightarrow c \uparrow \). One market shock can transmit to the other market through capital flows. Interest rate term spread differential \( c \) and CIP deviation \( b \) reflect in the same direction to either exogenous bond demand shocks \( \varepsilon_c \) or exogenous currency forward demand shocks \( \varepsilon_b \). RMB bond issuance \( \mu \) reflect oppositely to the two shocks.

**Proposition 2.** *(Issuance flow and net deviation)* \((c - b) \downarrow \Rightarrow \mu \downarrow\) Cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore.

**Proposition 3.** *(Arbitrage capital and aligned deviations)* Since \( \frac{\partial |c - b|}{\partial D} < 0 \) so that \( \lim_{D \to \infty} c - b = 0 \). A large amount debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations becomes identical.
4 Empirical results

Table 1: Data Description

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNY ($S_{on}$)</td>
<td>onshore spot exchange rate RMB/USD</td>
<td>D</td>
</tr>
<tr>
<td>CNH ($S_{off}$)</td>
<td>offshore spot exchange rate RMB/USD</td>
<td>D</td>
</tr>
<tr>
<td>DF ($F_{on}$)</td>
<td>1 year onshore deliverable forward exchange rate RMB/USD</td>
<td>D</td>
</tr>
<tr>
<td>NDF ($F_{off}$)</td>
<td>1 year offshore non-deliverable forward exchange rate RMB/USD</td>
<td>D</td>
</tr>
<tr>
<td>SHIBOR ($r_{a,ro/n}^a$, $r_{o/n}^a$)</td>
<td>Shanghai interbank offered rate (1 year and overnight)</td>
<td>D</td>
</tr>
<tr>
<td>HIBOR ($r_{a,ro/n}^o$, $r_{o/n}^o$)</td>
<td>Hong Kong interbank offered RMB rate (1 year and overnight)</td>
<td>D</td>
</tr>
<tr>
<td>Bond ETFs ($\mu$)</td>
<td>5-year bond ETFs traded in Shanghai and Hong Kong volume/amount</td>
<td>D</td>
</tr>
<tr>
<td>Shock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RRR ($\varepsilon_1^r$)</td>
<td>required deposit reserve ratio for Mainland China</td>
<td>D</td>
</tr>
<tr>
<td>CSI 300 ($\varepsilon_2^c$)</td>
<td>a blue chip index for top 300 stocks in Mainland China stock exchanges</td>
<td>D</td>
</tr>
<tr>
<td>HSI ($\varepsilon_2^h$)</td>
<td>a blue chip index for top 50 stocks in Hong Kong stock exchanges</td>
<td>D</td>
</tr>
<tr>
<td>R-REPO ($\varepsilon_3^r$)</td>
<td>reverse repurchase agreements in Mainland China open market</td>
<td>D</td>
</tr>
<tr>
<td>BAS ($\varepsilon_1^b$)</td>
<td>bid-ask spread for exchange rate CNY/USD and CNH/USD</td>
<td>D</td>
</tr>
<tr>
<td>DCPR ($\varepsilon_2^b$)</td>
<td>deviations between on/offshore spot RMB/USDs and central parity rate</td>
<td>D</td>
</tr>
<tr>
<td>CCI ($\varepsilon_3^c$)</td>
<td>capital control index by computation</td>
<td>D</td>
</tr>
</tbody>
</table>

Source: Bloomberg, FRED, Wind and China Bureau of Statistics

4.1 Dataset

This section uses empirical data to generate endogenous variables ($c$, $b$, $\mu$) and exogenous shocks ($\varepsilon_1^c$, $\varepsilon_2^b$) in the model. The period is from 11/3/2014 to 9/5/2018, daily data. Interest rate term spread differential $c = (r_{a,ro/n}^a - r_{o/n}^o) - (r_{a,ro/n}^o - r_{o/n}^o)$ is calculated by Shanghai interbank offered rate (1 year and overnight) and Hong Kong interbank offered RMB rate (1 year and overnight). This paper assumes overnight rate is risk free rate. Transaction cost CIP deviation $b = r_{o/n}^o + \frac{S_{on}}{S_{off}} - \frac{F_{on}}{F_{off}} - r_{o/n}^o$ is estimated by onshore and offshore risk free rate, and CNY/CNH spot and forward exchange rates which use RMB/USD as a connection. Capital flow onshore share $\mu = \frac{volume_{on}}{volume_{on} + volume_{off}}$ or $\mu = \frac{amount_{on}}{amount_{on} + amount_{off}}$ is measured by 5-year bond ETFs traded in Shanghai and Hong Kong (same underlying assets) volume/amount. The two methods are highly correlated ($\rho = 0.9997$), the paper would use volume calculated $\mu$ to measure capital flow. Exogenous bond demand shocks $\varepsilon_1^c$ in money market are caused by monetary policy, investor preference, and money market regulatory. Exogenous currency forward demand shocks $\varepsilon_2^b$ (non-issuance-related use of currency forward contracts) in currency forward market are influenced by central bank policy - FX intervention, trader expectation driven hedging and arbitraging demands, and...
4.2 Source of shocks

4.2.1 Money market shocks

Monetary policy People’s Bank of China sets reserve ratio to influence money supply. Commercial banks are required to hold reserves against their total reservable liabilities, rather than lend out or invest. Any changes in reserve ratio would cause money market shocks, which could affect bond demand because of the different responses in onshore and offshore money markets. For instance, central bank increases required reserve ratio (RRR) to reduce the money supply in the economy. Therefore, the risk-free rate rises and financial capital would flow from risky assets to safe assets. The older bonds with a relative low premium (original yield minus new risk-free rate) would become less attractive. Demand for the bonds would decline in both onshore and offshore money markets, because the low premium would not be worth taking on the risk. Due to different responses of investors, the offshore demand would reduce more than onshore, which is a negative shock on $\varepsilon_c$. Finally, the yield of bonds would rise until supply and demand reached a new equilibrium in each market, then interest rate term spread differential $c$ rises. This paper uses the changed RRRs as shocks in money market.

Investor preference The stock market is the crucial part of financial market to investors. CSI 300 is a blue chip index for top 300 stocks in Mainland China stock exchanges to measure the performance of onshore stock market. What’s more, HSI is a blue chip index for top 50 stocks in Hong Kong stock exchanges to measure the performance of offshore stock market. The detrended indices of daily log-form closing price are the cyclical components as shocks. The index shocks of both onshore and offshore markets are positive correlation ($\rho = 0.44$). A positive shock of offshore-relative-to-onshore stock market indices would cause capital inflow from bond market to stock market because of investor preference (seeking high return and low risk assets) and substitution effect. Therefore, the offshore-relative-to-onshore bond demand shock is negative $\varepsilon_c$. A new equilibrium of bond market has a higher yield $c$, which is consistent with the prediction of the model.

Money market regulatory People’s Bank of China could use a repurchase agreement (REPO) or a reverse repurchase agreement (Reverse REPO), classified as a money market instrument, to decrease or increase short-term liquidity as one of open market operations.
A positive shock of reverse repurchase agreement (R-REPO) means central bank increases short-term liquidity. In other words, central bank purchases bonds now and agrees to sell them in the future. Then, central bank pushes the traditional government bond investors in search of high-yielding bond. Therefore, onshore bond demand rises (offshore-relative-to-onshore bond demand drops), which has a negative impact on $\varepsilon_c$. The increasing short-term liquidity would trigger that onshore yield falls, so interest rate term spread differential $c$ rises.

4.2.2 Currency market shocks

Central bank policy People’s Bank of China can implement foreign exchange intervention through changing currency liquidity. The bid-ask spread is a reflection of the demand and supply for the asset. Due to the difference in liquidity of each asset, the size of the bid-ask spread from one asset to another varies. Here, this paper uses onshore and offshore RMB/USD exchange rate bid-ask spreads to measure the onshore-offshore CNY/CNH liquidity. The liquid asset has a small bid-ask spread in the currency market. A positive shock on CNY/CNH liquidity means that the spot exchange rate CNY/CNH currency market has less liquidity. From a currency market trader’s perspective, liquidity is usually experienced in terms of the volatility of price movements. A liquid asset will tend to see prices move very gradually and in small increments. An illiquid asset will tend to see prices move abruptly and in large price increments. When traders face risky currency market, non-issuance-related use of currency forward contracts $\varepsilon_b$ increases. Thus, the offshore strategy becomes costly, then the onshore-relative-to-offshore transaction cost (CIP basis) $b$ would fall.

Trader expectation In China’s onshore spot foreign exchange market, RMB is allowed to rise or fall by 2 percent from the central parity rate each trading day, but the daily trading band doesn’t impose on offshore foreign exchange market. Therefore, the risk could be from large uncertain movement of CNH/USD in offshore currency market. The gap of CNH/USD and central parity rate is divided by the gap of CNY/USD and central parity rate to measure offshore-relative-to-onshore exchange rate volatility. If the result is less than the threshold -2, the offshore exchange rate is more volatile than onshore one with the opposite direction.\footnote{Because the spot exchange rate between onshore CNY and offshore CNH is $1 + s \equiv \frac{S_{on}}{S_{off}}$, the CNY/CNH bid price is $1 + s^b \equiv \frac{S_{on}^b}{S_{off}^a}$ and the CNY/CNH ask price is $1 + s^a \equiv \frac{S_{on}^a}{S_{off}^b}$. However, the onshore-offshore liquidity gap used in this paper is the difference between onshore CNY/USD bid-ask spreads ($S_{on}^a - S_{on}^b$) and offshore CNH/USD bid-ask spreads ($S_{off}^a - S_{off}^b$).}

If $\frac{DCPR_{on}}{DCPR_{off}} < -2$, $\varepsilon_b = 1 + \frac{DCPR_{on}}{DCPR_{off}}$; otherwise, $\varepsilon_b = 0$. Therefore, $\varepsilon_b$ is between 0 (less risky) and 1 (more risky).
When traders see more volatile offshore market and opposite deviation from central parity rate against onshore market, they would use currency forward contracts $\varepsilon_b$ to hedge risk or pursue arbitrage opportunity. As the result, the excess demands of currency forward contracts increase the cost of offshore strategy, and CIP basis $b$ would fall.

**Currency market regulatory** Capital control represents any methods taken by People’s Bank of China to limit the capital inflow and outflow to and from the domestic economy. Capital controls can affect many assets such as bonds, stocks and foreign exchange trades. Because the de jure indices like IMF’s AREAER and Chinn-Ito with annual frequency would not reflect an effectiveness after a policy changing, this paper calculates a daily capital control index which follows the basic index construction method according to Schindler [2009] with 7 AREAER asset subcategories including portfolio equity investment, bond investment, money market investment, collective investment, derivative investment, commercial credits and real estate investment. The capital control index is between 1 and 0 to measure the degree from full capital controls to free capital flows. A positive shock of changed daily capital control index would cause more controls on free capital movement. The capital control could lower risks associated with the volatility of capital flows in onshore currency market, but this regulatory would expand the gap between offshore and onshore currency market. Consequently, the demands of currency forward contracts $\varepsilon_b$ increase, and onshore-relative-to-offshore CIP basis $b$ decreases.

<table>
<thead>
<tr>
<th>Table 2: Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_c$</td>
</tr>
<tr>
<td>Correlation $\downarrow$</td>
</tr>
<tr>
<td>c $\uparrow$</td>
</tr>
<tr>
<td>$\varepsilon_b$</td>
</tr>
<tr>
<td>Correlation $\downarrow$</td>
</tr>
<tr>
<td>b $\downarrow$</td>
</tr>
</tbody>
</table>

4.3 Proposition 1 test

4.3.1 Bayesian Local Projection Method

Miranda-Agrippino and Ricco [2017] provided a flexible econometric method - Bayesian local projections robust to misspecifications that bridges between vector autoregressions (VARs)
and local projections (LPs). The VARs produce IRFs by iterating up to the relevant horizon the coefficients of a one-step-ahead model. However, because of a small-size information set, underestimated lag order, and non-linearities, misspecified VARs can fail to capture all of the dynamic interactions. $y_{t+1} = C + B_1 y_t + \ldots + B_p y_{t-p+1} + \epsilon_{t+1}$ The LPs, Jordà [2005], estimate the IRFs from the coefficients of direct projections of variables onto their lags at the relevant horizon. However, due to the moving average structure of the residuals, and the risk of over parametrisation, LPs are likely to be less efficient, and hence subject to volatile and imprecise estimates. $y_{t+h} = C + B_1 y_t + \ldots + B_p y_{t-p+1} + \epsilon_{t+h}$ Therefore, choosing between iterated and direct methods involves a sharp trade-off between bias and estimation variance: the VAR produces more efficient parameters estimates than the LP, but it is prone to bias if the one-step-ahead model is misspecified.

Miranda-Agrippino and Ricco [2017] proposed a regularization for LP-based IRFs which builds on the prior that a VAR can provide, in first approximation, a decent description of the behaviour of most variables. As the horizon grows, however, BLPs are allowed to optimally deviate from the restrictive shape of VAR-based IRFs, whenever these are poorly supported by the data. This while the discipline imposed by the prior allows to retain reasonable estimation uncertainty at all horizons. Hence, BLP can sensibly reduce the impact of compounded biases over the horizons, effectively dealing with model misspecifications.

4.3.2 Impulse response functions

The main results of this section is that impulse response functions (IRFs) with two exogenous shocks differ along some important dimensions, using the VAR equation (11)$^4$. Figure 4 to Figure 6 show exogenous offshore-relative-to-onshore bond demand shocks from different sources in money market with Bayesian local projection method. Figure 7 to Figure 9 display exogenous non-issuance-related use of currency forward contracts shocks from different sources in currency market with Bayesian local projection method.$^5$

$^4$The VAR appendix shows the link between theoretical model and empirical equation.

$^5$All IRFs have 90% confidence interval. Variables pass augmented Dickey-Fuller test and conclude a stationary process. Akaike’s information criterion (AIC), Schwarz’s Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC) lag order selection statistics provide a optimal lag number 4. Please see the IRFs appendix for more details with other methods - VARs and LPs.
\[
\begin{bmatrix}
\omega & -D & D \\
2D & \tau & 0 \\
-D & 0 & \frac{1}{\gamma}
\end{bmatrix}
\begin{bmatrix}
\mu_t \\
c_t \\
b_t
\end{bmatrix} = B_0 + B_1 \begin{bmatrix}
\mu_{t-1} \\
c_{t-1} \\
b_{t-1}
\end{bmatrix} + B_2 \begin{bmatrix}
\mu_{t-2} \\
c_{t-2} \\
b_{t-2}
\end{bmatrix} + B_3 \begin{bmatrix}
\mu_{t-3} \\
c_{t-3} \\
b_{t-3}
\end{bmatrix} + B_4 \begin{bmatrix}
\mu_{t-4} \\
c_{t-4} \\
b_{t-4}
\end{bmatrix} - \begin{bmatrix}
0 \\
\varepsilon_{c,t} \\
\varepsilon_{b,t}
\end{bmatrix}
\] (11)

For money market shocks, Proposition 1 test, if \(\varepsilon_c \downarrow\), then \(c \uparrow \Rightarrow \mu \uparrow \Rightarrow b \uparrow\). In Figure 4, the changed reserve ratio would cause that simultaneous effect of a 1% increase in interest rate term spread differential (offshore-relative-to-onshore money market cost) will lead a 0.3% increase in the share of onshore bond issuance which would raise transaction cost by 0.85% (onshore-relative-to-offshore currency market cost). In Figure 5, stock market substitution effect influences term spread differential by a 1% rise, then offshore money market cost raises 1.1% of onshore transaction cost following by onshore issuance share 0.16% jump. In Figure 6, the result of reverse repurchase agreement operations is consistent with model prediction. 1% increase in \(c\) triggers around 1% increase in \(b\) through the more onshore issuance \(\mu\) by 0.5%.

![Graphs showing monetary policy effects](image)

Figure 4: Monetary policy - changed reserve ratio \(\varepsilon_c \downarrow\)
For currency market shocks, Proposition 1 test, if $\varepsilon_b \downarrow$, then $b \uparrow \Rightarrow \mu \downarrow \Rightarrow c \uparrow$. In Figure 7, CNY/CNH liquidity would cause that simultaneous effect of a 1% increase in trascation cost (onshore-relative-to-offshore currency market cost) will be a 2.5% decrease in the share of onshore bond issuance which would raise interest rate term spread differential by 1% (offshore-relative-to-onshore money market cost). In Figure 8, offshore-relative-to-onshore exchange rate volatility affects transaction cost by 1% increase, then onshore currency market cost raises 2% of offshore money market cost following by onshore issuance share 1.4% fall. In Figure 9, the result of capital control is consistent with model prediction. 1% increase in $b$ triggers around 3% increase in $c$ through the less onshore issuance $\mu$ by 3.5%.
In shorts, one market shock can transmit to the other market through capital flows. The spot money market is more sensitive to shocks from forward currency market through capital flows. The more significant capital flows under uncertainty shocks from forward currency
market would cause that transaction cost is more volatile, due to exchange-rate overshooting. The effects decay in a week after initial shocks, but the effect on capital flows is less persistent.

4.4 Proposition 2 & 3 tests

4.4.1 Long run propensity

The cumulative effect of a permanent change in \( X_t \) on \( Y_t \) will be the sum of the coefficients, known as the long run propensity (LRP). This paper uses Koyck (geometric lag) model to provide evidence of Proposition 2 and 3. This model allows for feasible estimation of \( Y_t = \beta_0 + \delta_0 X_t + \delta_1 X_{t-1} + \delta_2 X_{t-2} + \ldots + \delta_q X_{t-q} + \ldots + u_t \) under assumption that \( \delta_i = \delta_0 \lambda^i \) where \( 0 < \lambda < 1 \). Thus, the value of the impact multipliers (\( \delta_i \)) decreases geometrically as the associated lag (i) increases. A larger value of \( \lambda \) (closer to 1) means a greater persistence of lagged values. The estimation equation is \( Y_t = \beta^* + \lambda Y_{t-1} + \delta_0 X_t + u^*_t \), so the long run propensity is \( LRP = \frac{\delta_0}{1-\lambda} \). Therefore, this model shows not only simultaneous effect, but also cumulative effect (LRP).

4.4.2 Regression

Koyck (geometric lag) model tests Proposition 2 & 3 to estimate long run propensity, also involving endogeneity, heteroskedasticity, and auto-correlated errors problems. Therefore, this paper uses two stage least squares (2SLS) instrumental variables and robust standard errors method to solve these problems, also adds some control variables (\( \Delta RRR, HSI-CSI, R-REPO, BAS, DCPR, \Delta CCI \)) from money and currency markets into the estimation equation. For Proposition 2 with equation (12), the share \( \mu \) and gap \( c - b \) have endogenous problem, so the sixth lag of gap \( c - b \) is the instrumental variable for current gap \( c - b \). From Proposition 1 results, the sixth lag is deep enough for instrumental variable. The Proposition 2 test \((c - b) \downarrow \Rightarrow \mu \downarrow\) estimates insignificant \( \lambda_{p2} = 0.019 \) which implies little persistence, and significant \( \delta_{0,p2} = 0.305 \) as model prediction. As a result, simultaneous effect of a 1% decrease in offshore-relative-to-onshore bond issuance cost \( c - b \) will be a 0.305% decrease in the share of onshore bond issuance. Therefore, cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore.

\(^6\text{see Koyck model derivation appendix for more details}\)
\[
\mu_t = \beta_{p2}^* + \lambda_{p2}(c - b)_{t-1} + \delta_{0,p2}(c - b)_{t} + B_{p2}control\_variables_t + u_{p2,t}^* \\
|c - b|_t = \beta_{p3}^* + \lambda_{p3}|c - b|_{t-1} + \delta_{0,p3}\log(D_t) + B_{p3}control\_variables_t + u_{p3,t}^*
\]

(12)  

(13)

For Proposition 3 with equation (13), the sum of onshore and offshore bond ETFs amount is the total debt issuance with logarithmic form. Also, there is an endogenous problem. This regression chooses the third lag of \(\text{debt}\) as its instrumental variable. The Proposition 3 test \(\frac{\partial|c-b|}{\partial D} < 0\) provides significant \(\lambda_{p3} = 0.854\) which implies high level of persistence, and significant \(\delta_{0,p3} = -0.03\) as model prediction. The simultaneous effect of a 1% increase in total bond issuance will be a 0.03 basis point decrease in the absolute gap of interest rate \(|c - b|\). However, cumulative effect (LRP) of a 1% increase in total bond issuance will be a 0.205 basis point decrease in the absolute gap of interest rate \(|c - b|\). In a word, a large amount debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations becomes identical.

|  | \(\mu\_\text{share}\) | \(\mu\_\text{share}\) | \(\text{debt}\_\text{amount}\) | \(|c-b|\) |
|---|---|---|---|---|
| \(|c-b|\) | 0.305* | \(0.305^*\) | -0.030* | \(0.030^*\) |
| \(\text{control variables}\) | 0.019 | \(0.019\) | 0.854*** | \(0.854^{***}\) |
| \(\text{cons}\) | 97.634*** | \(97.634^{***}\) | 0.690** | \(0.690^{**}\) |
| \(\text{N}\) | 410 | \(410\) | 274 | \(274\) |
| \(\text{Root MSE}\) | 3.031 | \(3.031\) | \(0.273\) | \(0.273\) |

5 Conclusion

China has both RMB onshore and offshore markets. The onshore CNY market is relatively regulated and controlled, but the offshore CNH market is relatively marketized and liberalized. The offshore market is the experimental field of RMB internationalization. This asymmetric phenomenon would cause a lot of questions that are worth probing into. This paper implements idea of Liao [2016] to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential and CIP violation spillover effects. From model’s results, there are three propositions under the financial institution - bank’s strategy
in RMB money and currency markets. This paper also uses a flexible econometric method of Miranda-Agrippino and Ricco [2017], which can sensibly reduce the impact of compounded biases over the horizons and effectively deal with model misspecifications, to test Proposition 1 with different source of shocks. Another econometric method is two stage least squares (2SLS) instrumental variables and robust standard errors under Koyck (geometric lag) model to test Proposition 2 & 3 simultaneous effect and long run propensity.

The results are three-fold: First, Proposition 1 - spillover of deviations: one market shock can transmit to the other market through capital flows. The shocks from forward currency market have a large impact on the spot money market through capital flows. Also, these shocks from forward currency market would cause overreacted capital flows which makes transaction cost more volatile because of exchange-rate overshooting. The effects on both markets would die away in a week after initial shocks, but the effect on capital flows is less persistent. Second, Proposition 2 - issuance flow and net deviation: cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore. The profit maximization behavior of financial institutions could cause bond issuance movement to lower cost. Third, Proposition 3 - arbitrage capital and aligned deviations: a large amount debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations becomes identical. The asymmetric phenomenon implies RMB markets are less efficient, so there would be some arbitrage opportunities. However, strict regulations and large costs can turn a possible arbitrage situation into unfavorable one that has no benefit to investors and traders.
References


R Craig, Changchun Hua, Philip K Ng, and Raymond Yuen. Development of the renminbi market in Hong Kong SAR: Assessing onshore-offshore market integration. 2013.


Wenxin Du, Alexander Tepper, and Adrien Verdelhan. Deviations from covered interest rate parity. 2016.


Appendices

A Daily capital control index

The daily capital control index is calculated by the unweighted average index of following financial related categories in order to reflect the sensitivity of capital control policy changing. For each following financial related category, the index is between 1 and 0 where 1 means totally controlled and 0 vice versa (4th Jan 2010 is a benchmark date). If there is a policy change from full control to semi-open, the index becomes 0.5 from 1. Also, the index would be unchanged, if there is not a new released policy. The novel capital control index of China on a daily basis from 2010 to 2018 is based on the public information provided from SAFE website and PBoC annual policy reports.\footnote{Qing Ge calculates the daily capital control index.}

\footnotetext{\footnotesize\textsuperscript{7}}
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ka</td>
<td>Overall restrictions index</td>
</tr>
<tr>
<td>kai</td>
<td>Overall inflow restrictions index</td>
</tr>
<tr>
<td>kao</td>
<td>Overall outflow restrictions index</td>
</tr>
<tr>
<td>eq</td>
<td>Average equity restrictions</td>
</tr>
<tr>
<td>eqi</td>
<td>Equity inflow restrictions</td>
</tr>
<tr>
<td>eqo</td>
<td>Equity outflow restrictions</td>
</tr>
<tr>
<td>eq_plbn</td>
<td>Purchase locally by nonresidents (equity)</td>
</tr>
<tr>
<td>eq_slhn</td>
<td>Sale or issue locally by nonresidents (equity)</td>
</tr>
<tr>
<td>eq_pabr</td>
<td>Purchase abroad by residents (equity)</td>
</tr>
<tr>
<td>eq_siar</td>
<td>Sale or issue abroad by residents (equity)</td>
</tr>
<tr>
<td>bo</td>
<td>Average bond restrictions</td>
</tr>
<tr>
<td>boi</td>
<td>Bond inflow restrictions</td>
</tr>
<tr>
<td>boo</td>
<td>Bond outflow restrictions</td>
</tr>
<tr>
<td>bo_plbn</td>
<td>Purchase locally by nonresidents (bonds)</td>
</tr>
<tr>
<td>bo_slhn</td>
<td>Sale or issue locally by nonresidents (bonds)</td>
</tr>
<tr>
<td>bo_pabr</td>
<td>Purchase abroad by residents (bonds)</td>
</tr>
<tr>
<td>bo_siar</td>
<td>Sale or issue abroad by residents (bonds)</td>
</tr>
<tr>
<td>mm</td>
<td>Average money market restrictions</td>
</tr>
<tr>
<td>mmi</td>
<td>Money market inflow restrictions</td>
</tr>
<tr>
<td>mmo</td>
<td>Money market outflow restrictions</td>
</tr>
<tr>
<td>mm_plbn</td>
<td>Purchase locally by nonresidents (money market instruments)</td>
</tr>
<tr>
<td>mm_slhn</td>
<td>Sale or issue locally by nonresidents (money market instruments)</td>
</tr>
<tr>
<td>mm_pabr</td>
<td>Purchase abroad by residents (money market instruments)</td>
</tr>
<tr>
<td>mm_siar</td>
<td>Sale or issue abroad by residents (money market instruments)</td>
</tr>
<tr>
<td>ci</td>
<td>Average collective investments restrictions</td>
</tr>
<tr>
<td>cii</td>
<td>Collective investments inflow restrictions</td>
</tr>
<tr>
<td>cio</td>
<td>Collective investments outflow restrictions</td>
</tr>
<tr>
<td>ci_plbn</td>
<td>Purchase locally by nonresidents (collective investments)</td>
</tr>
<tr>
<td>ci_slhn</td>
<td>Sale or issue locally by nonresidents (collective investments)</td>
</tr>
<tr>
<td>ci_pabr</td>
<td>Purchase abroad by residents (collective investments)</td>
</tr>
<tr>
<td>ci_siar</td>
<td>Sale or issue abroad by residents (collective investments)</td>
</tr>
<tr>
<td>de</td>
<td>Average derivatives restrictions</td>
</tr>
<tr>
<td>dei</td>
<td>Derivatives inflow restrictions</td>
</tr>
<tr>
<td>/deo</td>
<td>Derivatives outflow restrictions</td>
</tr>
<tr>
<td>de_plbn</td>
<td>Purchase locally by nonresidents (derivatives)</td>
</tr>
<tr>
<td>de_slhn</td>
<td>Sale or issue locally by nonresidents (derivatives)</td>
</tr>
<tr>
<td>de_pabr</td>
<td>Purchase abroad by residents (derivatives)</td>
</tr>
<tr>
<td>de_siar</td>
<td>Sale or issue abroad by residents (derivatives)</td>
</tr>
<tr>
<td>di</td>
<td>Average direct investment restrictions</td>
</tr>
<tr>
<td>dii</td>
<td>Direct investment inflow restrictions</td>
</tr>
<tr>
<td>dio</td>
<td>Direct investment outflow restrictions</td>
</tr>
<tr>
<td>re</td>
<td>Average real estate restrictions</td>
</tr>
<tr>
<td>rei</td>
<td>Real estate inflow restrictions</td>
</tr>
<tr>
<td>reo</td>
<td>Real estate outflow restrictions</td>
</tr>
<tr>
<td>re_pabr</td>
<td>Purchase abroad by residents (real estate)</td>
</tr>
<tr>
<td>re_plbn</td>
<td>Purchase locally by nonresidents (real estate)</td>
</tr>
<tr>
<td>re_sibn</td>
<td>Sale locally by nonresidents (real estate)</td>
</tr>
</tbody>
</table>
B VAR

From equilibrium conditions of the static model:

\[ \mu = \frac{(c - b)D}{\omega} + \theta \]
\[ c = \frac{V}{\tau}((1 - 2\mu)D - \varepsilon_c) \]
\[ b = -\gamma^2((1 - \mu)D + \varepsilon_b) \]

Then, static model with time subscript in matrix form:

\[
\begin{bmatrix}
\omega & -D & D \\
2D & \frac{\tau}{V} & 0 \\
-D & 0 & \frac{1}{\gamma^2}
\end{bmatrix}
\begin{bmatrix}
\mu_t \\
c_t \\
b_t
\end{bmatrix}
= \begin{bmatrix}
\theta \omega \\
D \\
-D
\end{bmatrix} - \begin{bmatrix}
0 \\
\varepsilon_{c,t} \\
\varepsilon_{b,t}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\omega & -D & D \\
2D & \frac{\tau}{V} & 0 \\
-D & 0 & \frac{1}{\gamma^2}
\end{bmatrix}
= M
\]

Due to \( \text{det}(M) = \frac{\omega^2 + \gamma^2 D^2 + 2V D^2}{V \gamma^2} > 0 \) (In other words, \( M^{-1} \) is the inverse of matrix \( M \)), this system has solution.

Therefore, VAR with optimal lags:

\[
\begin{bmatrix}
\omega & -D & D \\
2D & \frac{\tau}{V} & 0 \\
-D & 0 & \frac{1}{\gamma^2}
\end{bmatrix}
\begin{bmatrix}
\mu_t \\
c_t \\
b_t
\end{bmatrix}
= B_0 + B_1 \begin{bmatrix}
\mu_{t-1} \\
c_{t-1} \\
b_{t-1}
\end{bmatrix} + B_2 \begin{bmatrix}
\mu_{t-2} \\
c_{t-2} \\
b_{t-2}
\end{bmatrix} + B_3 \begin{bmatrix}
\mu_{t-3} \\
c_{t-3} \\
b_{t-3}
\end{bmatrix} + B_4 \begin{bmatrix}
\mu_{t-4} \\
c_{t-4} \\
b_{t-4}
\end{bmatrix} - \begin{bmatrix}
0 \\
\varepsilon_{c,t} \\
\varepsilon_{b,t}
\end{bmatrix}
\]

Reduced Form VAR:

\[
\begin{bmatrix}
\mu_t \\
c_t \\
b_t
\end{bmatrix}
= M^{-1}B_0 + M^{-1}B_1 \begin{bmatrix}
\mu_{t-1} \\
c_{t-1} \\
b_{t-1}
\end{bmatrix} + M^{-1}B_2 \begin{bmatrix}
\mu_{t-2} \\
c_{t-2} \\
b_{t-2}
\end{bmatrix} + M^{-1}B_3 \begin{bmatrix}
\mu_{t-3} \\
c_{t-3} \\
b_{t-3}
\end{bmatrix} + M^{-1}B_4 \begin{bmatrix}
\mu_{t-4} \\
c_{t-4} \\
b_{t-4}
\end{bmatrix} - M^{-1} \begin{bmatrix}
0 \\
\varepsilon_{c,t} \\
\varepsilon_{b,t}
\end{bmatrix}
\]
C IRFs

Figure 10: Monetary policy - changed reserve ratio $\varepsilon_c \downarrow$

Figure 11: Investor preference - stock market substitution effect $\varepsilon_c \downarrow$

Figure 12: Money market regulatory - reverse REPO of open market $\varepsilon_c \downarrow$
Figure 13: Central bank policy - liquidity of currency market $\varepsilon_b \downarrow$

Figure 14: Trader expectation - volatility of currency market $\varepsilon_b \downarrow$

Figure 15: Currency market regulatory - capital control $\varepsilon_b \downarrow$
D  Koyck model derivation

Substitute $\delta_i = \delta_0 \lambda^i$ into $Y_t = \beta_0 + \delta_0 X_t + \delta_1 X_{t-1} + \delta_2 X_{t-2} + \ldots + \delta_q X_{t-q} + \ldots + u_t$, and lag one period:

$Y_{t-1} = \beta_0 + \delta_0 X_{t-1} + \delta_0 \lambda X_{t-2} + \delta_0 \lambda^2 X_{t-3} + \ldots + \delta_0 \lambda^q X_{t-q-1} + \ldots + u_{t-1}$

then multiply both sides of above equation by $\lambda$:

$\lambda Y_{t-1} = \lambda \beta_0 + \delta_0 \lambda X_{t-1} + \delta_0 \lambda^2 X_{t-2} + \delta_0 \lambda^3 X_{t-3} + \ldots + \delta_0 \lambda^q X_{t-(q+1)} + \ldots + \lambda u_{t-1}$

then use original equation minus this new equation:

$Y_t - \lambda Y_{t-1} = (1 - \lambda) \beta_0 + \delta_0 X_t + u_t - \lambda u_{t-1}$

estimate the model:

$Y_t = \beta^* + \lambda Y_{t-1} + \delta_0 X_t + u^*_t$

where $\beta^* \equiv (1 - \lambda) \beta_0$ and $u^*_t \equiv u_t - \lambda u_{t-1}$.

Therefore,

$$LRP = \sum_{i=0}^{n} \frac{\partial Y_t}{\partial X_{t-i}} = \sum_{i=0}^{n} \delta_i = \sum_{i=0}^{n} \delta_0 \lambda^i = \frac{\delta_0}{1 - \lambda}$$